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Review article

Wastewater from Washed Rice Water as Plant Nutrient Source: Current Understanding and Knowledge Gaps

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ABSTRACT

A significant wastewater source in every household is washed rice water (WRW) because it contains leached nutrients (from washing the rice prior to cooking) that could be used as fertilizer. The paper reviewed the current understanding of the potential use of WRW as a plant nutrient source. WRW was shown to increase vegetables growth, such as water spinach, pak choy, lettuce, mustard, tomato, and eggplant. Different researchers have used various amounts of WRW, and their results followed a similar trend: the higher the amount of WRW, the higher the plant growth. WRW has also been used for other purposes, such as a source of carbon for microbial growth. WRW from brown rice and white rice had nutrients ranging from 40-150, 43-16306, 51-200, 8-3574, 36-1425, 27-212, and 32-560 mg L^{-1} of N, P, K, Ca, Mg, S, and vitamin B1 (thiamine), respectively. Proper utilization of WRW could reduce chemical fertilizer use and prevent both surface and groundwater contamination and environmental pollution. However, only a few of the studies have compared the use of WRW with the use of conventional NPK fertilizer. The major drawback of WRW studies is that they lack depth and scope, such as determining the initial and (or) final soil physico-chemical properties or plant nutrient contents. Considering the rich nutrient content in WRW, it will impact plant growth and soil fertility when used as both irrigation water and plant nutrient source.

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Therefore, it is recommended that studies on WRW effect on soil microbial population, plant, and soil nutrient contents to be carried out to ascertain the sustainability of WRW use as a plant nutrient source.

Keywords: Irrigation, liquid fertilizer, plant growth, soil microbes, wastewater

INTRODUCTION

Washed rice water (WRW) refers to the water used in washing rice before the rice is cooked. Milled rice is washed prior to cooking to remove the bran, dust, and dirt from the rice (Juliano, 1993). But rice washing can remove a significant amount of water-soluble nutrients from the rice. Several studies as reviewed by Juliano (1985) have shown that rice washing can lose up to 7% protein, 65% crude fat, 30% crude fiber, 59% thiamine, 26% riboflavin, 60% niacin, 26% Ca, 47% P, 47% Fe, 11% Zn, 70% Mg, and 41% K via leaching from the rice. Although these losses mean fewer nutrients are available in the rice for human consumption, they also mean the WRW, now enriched by these leached nutrients, could be used as a liquid plant fertilizer and soil amendment. There are many claims on the beneficial effects of WRW as a plant fertilizer, but these claims are very often anecdotal, given without any support of strong scientific evidence.

Unfortunately, rigorous, and in-depth scientific studies on the specific use of WRW as a plant fertilizer are very scarce. Instead, the research focus and interests on WRW are mostly on its potential use for either human or animal health (e.g., use of washed rice water as a health supplement or medical treatment) or cosmetology purposes (e.g., use of washed rice water as a human facial, skin, and hair care). From our search of the literature, most of the research on the potential use of WRW for agriculture purposes appears to be done in Indonesia. Moreover, these studies are often reported in non-English (though some of these reports include abstracts in English). These reports are also not easily available, and they are mostly published in non-cited journals.

But why use WRW when there are conventional fertilizers available? Reusing washed rice water ought to be encouraged because its practice is a part of better water governance. Global freshwater demand is expected to increase by 55% by 2050 (Park, 2013). This increase is mainly due to detrimental climate change and increasing world population, driving the United Nation to advocate for more effective water governance. Wastewater, rather than just being discarded into the environment, is instead reused, treated, or recycled. The AQUASTAT database of the Food and Agriculture Organization of the United Nations (FAO) estimates more than half of the global freshwater withdrawals are simply discarded as wastewater into the environment (WWDR, 2016). Municipal water demand corresponds to 11% of the global freshwater withdrawal, but out of this, only 3% is consumed, with the remaining 8% simply discarded, unused, as wastewater. Used water is being generated by towns and cities, from domestic purposes. These activities represent a waste product that must be utilized downstream as a resource or otherwise safely disposed. The average volume of wastewater generated daily by human activities depends on the water availability in the house, cultural type, cost of water, and socioeconomic conditions (Kalavrouziotis, 2015). "United Nations Agenda for Sustainable Development 2030" additionally aims to manage and reduce the release of wastes and chemicals into the environment (FAO, 2015).

Amoro et al. (2019) stated that the increase in water scarcity has increased the interest in finding various ways for wastewater reuse. Recently, there is an increase interest in wastewater utilization for irrigation (Khalid et al., 2018). Water scarcity, together with soil erosion, land degradation, and climate change, are the main threats to crop productivity (Roy et al., 2011). The most significant contribution of wastewater reuse in agriculture is to reduce the pressure on freshwater sources (Jaramillo & Restrepo, 2017; Winpenny et al., 2013). The greatest global water user is agriculture, which consumes 70% of available water (Pimentel & Pimentel, 2007). Thus, wastewater reuse contributes to food safety; thereby, increasing agricultural production in regions experiencing water shortages (Corcoran et al., 2010). The reasons for wastewater reuse are two-fold: water for the ever-increasing world population and for agriculture activities (Pescod, 1992), which make it necessary and worth to initiate and support wastewater reuse projects all over the world (Kretschmer et al., 2002). Kretschmer et al. (2002) for instance, reported that wastewater has the potential in improving soil properties and increasing plant yield.

The use of wastewater has been reported to save 45 to 94% of fertilizer needed in alfalfa and wheat production (Balkhair et al., 2013). The effects of wastewater application on the soil nutrient status and nutrient use efficiency are also reported in crop production. It was observed that the yield of marketable fruit was higher with wastewater compared to the use of groundwater (Gatta et al., 2015a; Gatta et al., 2015b). Some other studies (Aghtape et al., 2011; Cirelli et al., 2012; Li & Li, 2009) have also indicated the efficacy and superiority of wastewater irrigation which could be attributed to their enriched nutrients content. The wastewater application on soil also affects the soil microbial activity either directly or indirectly by changing the soil physicochemical properties (Ibekwe et al., 2018; Oliveira & Pampulha, 2006).

Considering that rice is the second most widely grown cereal, and it is eaten by nearly half of the world's population (GRiSP, 2013), the practice of reusing WRW can potentially lead to considerable savings in water as well as fertilizer use. Consequently, less dependence on energy in today's environment of detrimental climate change. The use of biofertilizers is, therefore, a part of sustainable agriculture that was proposed to reduce the use of chemical fertilizers (Sairi et al., 2018).

This review has found only 41 papers or studies that specifically used WRW as a plant fertilizer or soil amendment. But only about 10% of these papers were published in indexed journals, and the others: 61% in non-indexed journals and 29% in student research reports. This breakdown of papers indicates a lack of in-depth study on the potential use of WRW. The objective of the paper was to review these studies to determine our current understanding on WRW and its potential use as organic liquid plant fertilizer, identify the knowledge gaps, and finally recommend future research.

RICE TYPES

There are many rice forms, such as rough rice, brown rice, parboiled rice, regular milled white rice, pre-cooked rice, quick-frozen rice, and crisped, puffed or expanded rice (Kanchanawongkul, 2004). The mineral composition of rice differs according to rice variety, rice fertilization and cultivation, rice processing and cooking, and the soil type on which the rice is grown (Abbas et al., 2011; Roy et al., 2011). The parboiling in rice processing helps to retain some of the nutrients, where milling losses and rice recovery (whole rice kernels after milling) are energy-and labor-intensive activities (Roy et al., 2011). Brown rice is unmilled rice with its bran still intact. It is whole grain rice with an intact bran layer having its inedible outer hull removed (Upadhyay & Karn, 2018). Many researchers have reported that brown rice has a higher nutrients content than white rice (Babu et al., 2009; Pascual et al., 2013). Essential nutrients like iron, manganese, phosphorus, zinc, thiamine, niacin, vitamin E, dietary fiber, protein, and carbohydrate are higher due to the presence of an unremoved bran layer (Babu et al., 2009; Pascual et al., 2013). Red rice is considered as a weed in many countries, such as Greece, Latin America, Spain, and other temperate regions where this rice is grown with white rice (Patindol et al., 2006). However, in some countries, such as Sri Lanka and the Philippines, red rice is grown as a staple rice cultivar (Itani & Ogawa, 2004). Red rice is gaining popularity in Japan as a functional food because of its high polyphenols and anthocyanin content (Itani & Ogawa, 2004; Ling et al., 2001). White rice is known to have a higher glycemic index than other types of staple foods such as brown rice, whole grain, and barley (Helmyati et al., 2020). Black rice is one of the new rice that has a lower patronization rate (Helmyati et al., 2020). Together with brown rice, black rice is higher in fiber and antioxidants than white rice (Hernawan & Meylani, 2016).

WASHED RICE WATER AND WATER GOVERNANCE

Agricultural wastes are abundant in every country, with over 2 billion tons of household wastes generated globally, with more than 60 tons every second in the year 2020 (World Count, 2020). Malaysia produces about 2.6 million tons of agricultural wastes per year (Sreenivasan et al., 2012). It is estimated that about 3 million tonnes of rice are consumed yearly by Malaysians (Bee, 2019). As a conservative estimate, this works out to at least 3 billion L of WRW produced per year by Malaysians, and this amount is unused and simply discarded. So, it would be beneficial if these wastes could instead be utilized to reduce environmental pollution and to increase soil fertility. Different authors have reported an increase in total organic carbon (TOC) and nitrogen due to irrigation using wastewater, depending on the amount of organic matter in the wastewater (Jaramillo & Restrepo, 2017; Sun et al., 2014).

The indiscriminate disposal of WRW is harmful to the environment (e.g., via N and P pollution) (Siagian, 2018). Based on the reported nutrient content of the WRW in Table 1, it is evident that it is a potential source of contamination of our water sources (He et al., 2016b). Suryana et al. (2017) classified WRW as a waste considered insignificant or unimportant by the Indonesian public. The growing concern about the negative impacts of urban wastewater on the environment to reduce pollution has forced researchers to look for new and effective recycling alternatives (Santos et al., 2017). WRW from the household can serve as organic fertilizer for plant use (Iskarlia, 2017); besides, it can improve and increase soil fertility (Supraptiningsih et al., 2019) and use as an amendment (Brown et al., 2011; Cogger, 2005; Lehmann, 2011).

Many places around the world discharge domestic wastewater into natural waters. Zou et al. (2012) reported about 96% of villages in China would simply discard domestic wastewater, which have contaminated natural water bodies. Winance et al. (2018) reported production of 4 L of WRW by every household in Baomekot Village being thrown every day as waste, which can be utilized as irrigation water. Consequently, a few WRW reuse communal programs have been established, such as in Lambangkuning Village, Indonesia (Supraptiningsih et al., 2019). This village comprised about 30 households, and each of them produced about 5 L of WRW every day, making 150 L per day. The WRW is collected from every household, pooled, and used to irrigate the garden crops in the village and homes. Another communal WRW program is in Polo Geulis, a village in Central Bogor, Indonesia, which practices a centralized water-saving system. WRW is collected from the town citizens, after which the water is used to irrigate and fertilize their neighborhood crops of herbs and vegetables (The Jakarta Post, 2017).

Washed Rice Water as Fertilizer

The global mineral fertilizer demand increases every year because its demand is affected by population and economic growth, agriculture production and governance, and food price (FAO, 2015). Compared with mineral fertilizers, organic fertilizer has a longer-term effect on soils and plants, and it is claimed to be more environmentally friendly (Chandini et al., 2019; Sairi et al., 2018; Shaviv, 2001). However, one of the shortcomings of organic fertilizer is its slower effect on plants than inorganic fertilizers due to the slower release of organic fertilizers' nutrients. Among the organic fertilizers, liquid organic fertilizer is regarded to be better as the nutrients are applied in liquid soluble forms that can easily be absorbed by plants (Duaja et al., 2012). However, the nutrients release rates must match the plant nutrient uptake; otherwise, these nutrients, if not retained in the soils, may be lost via leaching.

Recent researches have shown that WRW can be used as a plant nutrient source as indicated by Bahar (2016), Wardiah and Hafnati (2014), Suryana et al. (2017), Hairudin (2015), Fitriani (2019), Hariyadi (2020), Handiyanto et al. (2013) and Leandro (2009). The presence of carbohydrates, proteins, vitamins, and other minerals at different concentrations in the WRW (Juliano, 1985; Purnami et al., 2014), depends on several factors, such as the rice variety, rice sources, and rice washing intensity (Akib et al., 2015; Purba et al., 2015; Purnami et al., 2014). Gibberellin and auxin are the two most common hormones employed in stimulating plant growth and both are reported to be present in WRW by Leandro (2009). Andrianto (2007) also attributed the increase in Adenium's plant roots to the presence of vitamin B1 in the WRW, which stimulated the plant growth into having greater root biomass. Vitamin B1 (Thiamine) applied once every two days combined with KNO_3 fertilizer increased the vegetative growth of *Dendrobium* sp. (orchid) seedlings (Sianipar, 2004).

The use of WRW as a plant nutrient source could reduce chemical fertilizer procurement and pollution. Kalsum et al. (2011) reported that fermented WRW contains numerous nutrients that are essential to plant growth and development. Carbohydrate is the most abundant content in WRW, by up to 300 mg L^{-1} (Kalsum et al., 2011; Nurhasanah et al., 2010). Dini and Salbiah (2019) found WRW have nutrient contents large enough to increase the vegetative and physiological growth of pepper after being fermented with cellulolytic bacteria. Generally, the efficiency of wastewater as a crop nutrient source largely depends on the soil fertility level, type and nutrient requirement of the crop, and the nutrients in the wastewater. The nutrient use efficiency for wastewater is high (Khalid et al., 2018). This is because the nutrients present in wastewater are commonly found in a dissolved form and, therefore, they are readily available for plant uptake (Khalid et al., 2017). Moreover, the wastewater-induced nutrient supply matches the demand of crops because nutrients are supplied with each irrigation, compared to synthetic fertilizers usually applied to crops in splits (Khalid et al., 2017; Sadaf et al., 2017).

An evaluation of WRW on the growth of both tomato and eggplant at different concentrations of the WRW gave a significant higher yield of their test crops such as in plant height, leaf number, and fresh plant weight (Istiqomah, 2012; Ariwibowo, 2012). Likewise, Karlina et al. (2013) compared the growth of spinach using different organic fertilizers and found WRW treatment to have a significant higher plant height than others. Consequently, they attributed the higher growth and yield to the higher nutrient contents of the WRW as well as the presence of a plant growth hormone (auxin).

However, WRW studies are often plagued by common inadequacies such as the absence of an initial and final soil analysis (e.g., Hairudin, 2015; Hariyadi, 2020) and lack of detailed description of the WRW application timings and methodology of the WRW preparation (e.g., Handiyanto et al., 2013; Hikmah, 2015), soil physicochemical and microbial properties, and the application area (e.g., Ariwibowo, 2012; Fitriani, 2019), as well as lack of comparisons between WRW treatments with conventional fertilizers such as NPK (e.g., Bahar, 2016; Dini & Salbiah, 2019; Ginting et al., 2017; Wulandari et al., 2012).

Washed Rice Water as a Potential Environmental Pollutant

Urban runoff and stormwater can, in some instances, find their way into sewage works (Duncomb et al., 1982). Industrial contamination is a major problem with sewage sludge; however, domestic sewage is also a potential significant contaminant (Naidu et al., 2004). Lack of such wastewater utilization practices will have adverse effects on nearby freshwater ecosystems and groundwater (He et al., 2016b). Moreover, biochemical oxygen demand (BOD) is high in WRW (2715 to 3800 mg L^{-1}) produced from industrial rice washing before use in food processing (He et al., 2016a). Starch, proteins (mainly composed of glutelin), and vitamins are the main solid particles composition of WRW (Watanabe et al., 2013). Malaysian soils are typically low in soil organic matter and have low cation exchange capacity (Shamshuddin, 1989). Consequently, the country's soils have inherently weak retention of nutrients that could increase the risk of large losses of nutrients via leaching. Leaching is a serious problem because large amounts of nutrients being leached out from the soil could pollute the groundwater and other water sources. The nutrient analyses of WRW show that it could be of greater concern due to its P and N content that can cause eutrophication and groundwater contamination, respectively (Table 1), upon their accumulation. The primary causes of groundwater contamination by nitrogenous compounds are landfill leachates (Nooten et al., 2008) and nitrogen-based fertilizer used in agriculture and uncontrolled wastewater discharge (Ghafari et al., 2008).

The treatment of wastewater generally requires a sewage system and a costly wastewater treatment plant (Kretschmer et al., 2002). One reason for this is it requires constant supply of power that may not always be available in some countries (Kretschmer et al., 2002). He et al. (2016a) reported that WRW have NO_3^-, NO_2^-, NH_4^+, total N, and total P in the range of 4.19 to 10.14, 0 to 0.08, 2.57 to 39.72, 51.26 to 84.79, and 23.41 to 58.12 mg L^{-1}, respectively. He et al. (2019) further used WRW for denitrification as a source of carbon for the microorganisms, which has a NO_3^-, NO_2^-, NH_4^+, total N, total P, and total organic carbon 0.63, 0.04, 0.17, 66.82, 33.96 and 495 mg L^{-1}, respectively. The presence of ammonia might be due to the degradation of WRW by microbes as stated by He et al. (2019). Deepa et al. (2008) reported that rice grains contain 7.95-9.52 g of protein 100 g^{-1} of rice grains, which is second to carbohydrate (72.8-74.1 g 100g^{-1} of rice grains). The analyses by Deepa et al. (2008) indicated WRW could have a significant amount of protein, and the protein degradation would produce ammonium via ammonification (Jones & Kielland, 2012).

Table 1
Nutrient contents of washed rice water and other commonly utilised organic amendments

References	Nutrient contents (mg L^{-1})										
	N	P	K	Ca	Mg	S	Fe	B	Vit. B1	Vit. K	Protein
Brown rice water											
Juliano (1993); Syuhaibah (2017); Wulandari et al. (2012)	47-140	62-14452	78-200	12-3574	66-1328	50-114	257-698	—	431-560	—	—
White rice water											
Wulandari et al. (2012); Syuhaibah (2017); Nurhasanah (2011).	40-150	43-16306	51-200	8-2944	36-1425	27-212	49-427	—	32-430	—	—
Dini and Salbiah (2019)	400	280	1000	—	—	—	—	—	—	—	—
Diana (2016)	70	60	90	—	—	—	10	6	210	10	180
Diana (2016) ++	12000	11000	5000	—	—	—	—	—	—	—	—
Malakar and Banerjee (1959)	440	300	—	2000	—	—	600	—	5000	—	—
Organic amendments (%)											
POME (Madaki & Seng, 2013; Razali et al., 2012; Sakiah & Wahyuni, 2018; Teh, 2016)	0.075-2.5	0.018-0.8	0.227-4	0.43-1.91	0.07-1.2	—	—	—	—	—	—
SS (Schulz & Römheld, 1997; Sommers, 1977)	<0.1-17.6	<0.1-14.3	0.02-2.64	0.1-25	0.03-1.97	0.6-1.5	—	—	—	—	—
EFB (Madaki & Seng, 2013; Moradi et al., 2014)	0.8-0.87	0.05-0.08	1.51-1.89	0.2-0.64	0.07-0.12	—	—	—	—	—	—
Compost (Harrison, 2008; Sullivan et al., 2018)	0.4-3.5	0.2-1.5	0.4-1.5	1.5-3.5	0.27-0.7	0.25-0.8	—	—	—	—	—

Note: ++, biofertilizer using fermented WRW; POME, palm oil mill effluent; SS, sewage sludge; EFB, empty fruit bunch; —, not determined

Washed Rice Water Nutrient Contents and its Effect on Plant Growth

Researchers have tested WRW on several crops which is shown in Table 2. They found that WRW increased the plant height, stem diameter, and yield of several crops such as: tomato (Ariwibowo, 2012; Hariyadi, 2020; Istiqomah, 2012; Leandro, 2009), water spinach (Bahar, 2016; Karlina et al., 2013; Syuhaibah, 2017), eggplant (Bukhari, 2013; Yulianingsih, 2017), and pak choy (Wardiah & Hafnati, 2014). WRW was also reported to have increased the lettuce yield and root weight (Siagian, 2018; Wulandari et al., 2012). It also increased the growth of mushroom (Handiyanto et al., 2013; Kalsum et al., 2011), height and leaf number of Adenium plant (Andrianto, 2007), chili (Sairi et al., 2018), as well as mustard green plants (Hairudin, 2015).

Wulandari et al. (2012) attributed the higher root growth of lettuce to the high sulfur (S) content (270 mg L^{-1}) present in the WRW (Table 2), in which S helps in thiamine synthesis. Thiamine (Vitamin B1) is an essential component of plant stress responses, disease resistance, crop yield, and several non-coenzyme roles of this vitamin are being characterized (Fitzpatrick & Chapman, 2020). As shown in Table 1, when WRW is compared with organic material (OM), particularly liquid OM, WRW is a good plant nutrient source. However, despite lower nutrient contents than compost and sewage sludge, it is at par with EFB and POME for N, P, Ca, and Mg nutrients. This indicated that WRW could make a significant impact when simultaneously used as irrigation water and plant nutrient source (Kalsum et al., 2011; Karlina et al., 2013; Lestari, 2010; Nurhasanah, 2011; Wardiah & Hafnati, 2014).

WRW will ferment over time. The maximum fermentation time tested was 6 days (Akib et al., 2015), where the fermented WRW was found to produce higher ethanol, phosphorus, nitrogen, and sulfur. Dini and Salbiah (2019) reported the nutrient contents of WRW fermented with a cellulolytic bacterial consortium to be 400, 280, and 1000 mg L^{-1} of N, P, and K, respectively. The relatively higher amount of N, P, and K, as compared with Wulandari et al. (2012), Syuhaibah (2017), and Nurhasanah (2011), could be attributed to the presence of the bacteria in the work by Dini and Salbiah (2019). Likewise, presence of bacteria capable of fixing atmospheric N and P, K solubilization could be why it has higher N and P (Table 1) as compared to the domestic waste used by Vermaat and Hanif (1998). Compared with the general nutrients content of other soil amendments such as EFB and compost (Table 1), WRW is a compatible plant nutrient supplement with the others. The commonly used soil amendments are compost and peat moss (Harrison, 2008; Sullivan et al., 2018), which compared with WRW, have higher N content by dry weight (3-1%), but have lower plant available N forms of 0.05 nitrates and 0.01% ammonium (Harrison, 2008).

Diana (2016) recorded high N (1.2%) content in fermented WRW (fermented with sugar and milk) for the development of biofertilizer (Table 1). Significant variability exists more in the N content in the WRW, with some authors reporting as high as 1.2% (Diana,

Table 2
Effect of washed rice water (WRW) on the growth of different crops

Type of WRW	Crop type	Rates	Results	Reference
WR water	*Capsicum annuum*	10 mL from different rice brand	Higher plant height leaves number and fresh weight, which was at par with liquid NPK fertilizer.	Sairi et al. (2018)
WR water + Goat manure	*Brassica nigra*	10, 20, and 30 mL of WRW and 5, 10, and 15 g of manure	The interaction was not significant, but higher plant height and leaves number was obtained by using 20 mL + 15g of goat manure	Amalia and Chitra (2018)
WR water + eggshell, WR water + Cassava peels, WR + eggshell + MSG waste and WR water + market waste, WR water + MSG + AC water	*Lycopersicon esculentum, Annona muricata, Elaeis guineensis* seedlings, *Brassica nigra,*	0, 50, 75, and 100 mL of WRW and 0, 10, and 20g of eggshell	Increased leaf number, plant height, stem diameter, and fresh and dry weight resulted in a 9-24% increase compared to control.	Winance et al. (2018); Hikmah (2015); Iskarlia (2017); Suryana et al. (2017); Ariwibowo (2012); Hariyadi (2020)
WR and BR water	*Phalaenopsis orchid seedlings.*	Application frequency of 2, 4, 6, and 8 days	Greater above-ground biomass was obtained at two days application interval with BR water. 11% percent increased BR than WR water was obtained.	Purnami et al. (2014)
WR water, WR + BR water	*Brassica rapa, Spinacia oleracea, Lactuca sativa*	-	The use of WRW did not increase the growth of pak choy and spinach	Fitriani (2019); Syuhaibah (2017); Wulandari et al. (2012)
BR water	*Apium graveolens, Capsicum spp.*	0, 100, 200, 300 and 400 mL	The use of BR water increased the growth of their test plants by 7-24%.	Istiqomah (2010); Baning et al. (2016)
WR water	*Lycopersicon esculentum, Solanum melongena, Spinacia oleracea.*	0, 0.5, 1 and 1.5 L	Increase the fresh and dry weight with 7-19% relative to the control and increase in plant height, leaves number, leaf length in the range of 22-43%.	Ratnadi et al. (2014); Leandro (2009); Bahar (2016)
WR water	*Brassica nigra.*	0, 5, 10, 15 and 20 days of fermented WR water	Higher plant height, total chlorophyll, and fresh weight in 0 and 15 days of fermentation. 3-9, 8-11, and 9-16% increase in chlorophyll and fresh weight 0 days more than in 5, 10, and 20 days of fermentation, respectively.	Wijiyanti et al. (2019)

Table 2 *(continue)*

Type of WRW	Crop type	Rates	Results	Reference
WR water	*Brassica nigra.*	0, 5, 10, 15 and 20 days of fermented WR water	Higher plant height, total chlorophyll, and fresh weight in 0 and 15 days of fermentation. 3-9, 8-11, and 9-16% increase in chlorophyll and fresh weight 0 days more than in 5, 10, and 20 days of fermentation, respectively.	Wijiyanti et al. (2019)
WR water	*Brassica rapa, Brassica nigra, Lycopersicon esculentum, Solanum melongena, Pleurotus ostreatus, Lactuca sativa, and Adenium obesum.*	0, 25, 50, 75 and 100 %	12-26% increase in plant growth with a range of 11-23, 9-14, and 6-15% increase in fresh weight, dry weight, and plant height.	Wardiah and Hafnati (2014); Hairudin (2015); Istiqomah (2010); Bukhari (2013); Yulianingsih (2017); Siagian (2018); Kalsum et al. (2011); Handiyanto et al. (2013); Andrianto (2007); Karlina et al. (2013)
WR water	*Capsicum spp.*	0, 10, and 15 mL of WR water, coconut water, and tofu waste were used.	Higher plant growth in using sole tofu waste at 10 mL concentration. There was a 7% decrease in the chili plant height when compared with the use of WR water at all levels	Dini and Salbiah (2019)

Note: WR, white rice; BR, brown rice; MSG, monosodium glutamate; AC, air conditioner

2016) while others far below 0.01% (Wulandari et al., 2012). These differences could be associated with the inadvertent fermentation of the WRW or differences in the rice washing intensity. When WRW is fermented, the complex compounds are broken down, which could lead to greater nutrient content. Wastewater irrigation in soil altered the ammonia-oxidizing bacterial population making the *Nitrosospira* and *Nitrosomonas* species dominant (Mechri et al., 2008). It is reported that wastewater containing an average concentration of 35 mg L^{-1} of N, 10 mg L^{-1} of P, and 30 mg L^{-1} of K, mostly meets many crops' requirements, particularly vegetables (Kalavrouziotis, 2015). Overall, the results showed that the nutrient content, particularly N, P, and K (Table 1), are within the range expected to impact plant growth and development by Kalavrouziotis (2015).

WRW can either be applied on a sole basis or in combination with other organic wastes with irrigation water. When applied with other organic wastes WRW generally showed significantly higher crop yields, particularly at higher WRW application rates (Table 2). Sairi et al. (2018) used NPK in the growth of chili seedlings and found it to be on par with fermented WRW, which led them to conclude that fermented WRW can be used as NPK replacement. Hariyadi (2020) substantiated it with a recent study that reported that WRW performed better than monosodium glutamate and air conditioner's water on tomato's growth (Table 2).

Comparison between White and Brown Rice Washed Water on Plant Growth

Few studies compared WRW from white (WR) and brown rice (BR) on plant growth. Wulandari et al. (2012) reported WRW from both BR and BR had non-significantly increased the fresh and dry weight of lettuce as compared with just using tap water. Between the two types of WRW, WR water improved the fresh weight of the crop more significantly at an early stage, but at harvest, there was no significant difference than the BR water-treated plants. When WR and BR water were compared with tap water (control), higher roots dry weight was recorded in both WR and BR water, which differed significantly from control. Wulandari et al. (2012) and Syuhaibah (2017) reported no overall significant difference between WRW and tap water in lettuce and spinach growth, respectively (Table 2).

Purnami et al. (2014) evaluated the use of WR and BR water on the growth of *Phalaenopsis* orchid nursery and found the use of BR water once every four days increased the total fresh weight, root length, plant height and higher above-grown biomass more than the WR water. Fitriani (2019) studied the effect of different sources of WRW on the growth of pak choy at different concentrations but found no significant difference between the WRW types on the growth of the plant. This indicates that the WRW had met the nutrients requirement of pak choy enough to support its metabolism and growth. Istiqomah (2010) stated that BR washed water had a significant effect on the increase in plant height and number of leaves of celery plants. The results of Baning et al. (2016) showed the effect of

BR water at different concentrations on the growth of pepper plants and found to increase the number of leaves, fresh and dry weight and recommended its use on the growth of pepper (Table 2).

Effect of WRW on Microbial Growth

Juwarkar et al. (1988) found populations of soil bacteria, fungi, and actinomycetes increased with increasing domestic wastewater applications. An increase in *Azotobacter* soil population was also observed due to the wastewater application (Juwarkar et al., 1988). Other than for fertilizer, WRW has also been studied for its potential use as a growth media for the bacteria *Bacillus thuringiensis* (Blondine & Yuniarti, 2008) and an alternative media carrier for *Pseudomonas fluorescence.* These bacteria help to control rust disease and to stimulate the growth of plants (Nurhasanah et al., 2010). Fermentation of WRW can be aided using microorganisms such as *Rhizopus, Aspergillus., Mucor, Amylomyces., Endomycopsis, Saccharomyces, Pichia anomala, Lactobacillus,* and *Acetobacter* (Akib et al., 2015). The fermentation process helps break down the complex structure of carbohydrates into other simpler compounds such as bioethanol and other elemental forms of the compound that could easily be used by the plants. WRW can support the growth of useful microorganisms (bacteria) such *as Rhizobium, Azospirillum, Azotobacter, Pseudomonas, Bacillus* for plant growth, and soil fertility increased (Akib et al., 2015). Amalia and Chitra (2018) reported the presence of *Pseudomonas fluorescence* bacteria among other microorganisms in WRW. It is a potential biocontrol agent that adapts well to plant roots and can help plants fight against pathogens or be resistant to disease (Hoffland et al., 1996). Furthermore, the bacteria mentioned above can produce phytohormones, which stimulate growth and increases cell enlargement. These microbes play a role in controlling pathogens that cause rust and triggering the plant growth to be more effective (Hairudin, 2015). Sairi et al. (2018) reported that *Bacillus spp*. and *Lactobacillus spp.* to be the common genus in WRW upon fermentation. Ahemad and Kibret (2014) reported using both genera to increase plant growth either as biofertilizer or as a biocontrol agent against plant disease. However, WRW not only supports the growth of bacteria but also several fungi species, such as *Trichoderma*. *Penicillium* and *Saccharomyces*, found upon fermentation for seven days, these fungi are beneficial to plant growth (Sairi et al., 2018). WRW has also been used as growth media for lactic acid bacteria (Watanabe et al., 2011; Watanabe et al., 2009).

LIMITATIONS

To our knowledge, this paper is the first review the specific use of WRW as a plant fertilizer. Most of the prior studies on WRW were done at the diploma and undergraduate level, which together with non-peer reviewed journals, made up 90% WRW studies. Only 10% of the 41 WRW studies were published in peer-reviewed journals. For this review, the use of students' reports and non-indexed journals were inevitable because of the lack of literature on the WRW use as a plant fertilizer. This indicates a knowledge gap in WRW reuse in agriculture.

Most WRW studies did not report the application frequency of the WRW, how WRW was applied, or even the area of the field or plot used. Furthermore, most of the WRW studies did not carry out the chemical analyses on the WRW used; neither did they analyze the initial and final plant and soil nutrient content. Consequently, it is unknown if, or by how much, the WRW had increased the nutrient content of the various test crops and soils due to WRW application alone. The effect of WRW on many basic soil physicochemical properties was also not measured. All their studies were focused only on a limited number of plant growth parameters. WRW studies that did WRW nutrient analyses examined only the macronutrients (N, P, K), none on the micronutrient contents, with few comparisons with NPK mineral fertilizer. WRW studies so far have all been to examine WRW effects over a short-term period (e.g., one planting cycle). But WRW may have a long-term impact on the soil nutrients as well as the soil microbial population. Although many research papers on WRW lack scientific robustness, they remain useful because their findings, at best, suggest that WRW can be beneficial to plant growth and yield as well as increase beneficial soil bacteria for soil health.

CONCLUSIONS AND RECOMMENDATIONS

WRW contains nutrients that could supplement conventional fertilizers (Table 1). It was reported to increase the growth of many crops ranging from the above to below-ground biomass (Table 2). Furthermore, it has also been used in combination with other wastes and was observed to increase plant growth. Various rates of the WRW have been used, with no reported negative effects even at high WRW rates. WRW appears suitable as a supplemental organic fertilizer to other organic and chemical fertilizers. Thus far, the severe limitation on WRW research is the lack of scientific rigor, lack of research methodology description, and, most importantly, the bulk of the study was published in non-indexed reports. Therefore, the results from these researches are at best tentative.

The following is recommended for a detailed evaluation of WRW as organic fertilizer, soil amendment, and source of soil microbial population increase:

1. Soils should be subjected to initial and final physicochemical and nutrient analyses to ascertain how the use of the WRW would alter the soils.
2. Soil microbial study should be incorporated in the study of WRW, particularly the soil microbial population, as WRW contains minerals and compounds essential for their growth and multiplication.
3. Long-term studies over several planting cycles on WRW should be conducted.

4. Periodic soil nutrient content and microbial population should be carried out to ascertain the temporal effect of WRW, particularly over prolonged periods.
5. The use of WRW should be compared with the use of conventional mineral fertilizer and other organic soil amendments (such as composts and palm oil mill effluent).

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